Multiplexed EUV Sources based on a Compact Module with High Irradiance and Low Etendue for Metrology Applications

Peter Choi, Sergey V. Zakharov [+], Raul Aliaga-Rossel, Adrice Bakouboula, Otman Benali, Philippe Bove, Michele Cau, Grainne Duffy, Carlo Fanara, Wafa Kezzar, Blair Lebert, Keith Powell, Ouassima Sarroukh, Luc Tantart, Clement Zaepffel, Vasily S. Zakharov

NANO-UV sas, 16-18 av du Québec, SILIC 705, Villebon/Yvette 91140, France
EPPRA sas, 16 av du Québec, SILIC 706, Villebon/Yvette 91140, France

[+] also with RRC Kurchatov Institute, Moscow, Russia

2010
International
Workshop on
EUV Sources
UCD, Dublin
Ireland

OUTLINE

- High brightness EUV sources are required
- NANO-UV compact EUV source module
  - enhanced plasma radiance in resistive regime
  - module characteristics
  - progress over the last six months
  - highly charged Xe ion EUV emission
- Multiplexing principles & realization
  - HYDRA^{4}-ABI™ prototype system
  - HYDRA^{12}-AIMS™ source prototype

Remaining Focus Areas

EUVL Symposium, Prague 2009	EUVL Symposium, Kobe 2010
1 - Mask yield & defect inspection/review infrastructure	1 - Mask yield & defect inspection/review infrastructure
2 - Long-term source operation with 115 W at the IF for 5mJ/cm^2 resist sensitivity or with 200W at the IF for 10mJ/cm^2 resist sensitivity	(for 22nm HP) 2 - Long-term source operation with 200W at the IF for 10mJ/cm^2 resist sensitivity
3 – Resist: resolution, sensitivity, LER	3 – Resist: resolution, sensitivity, LER

- **light source for Litho and mask inspection critical** -

Metrology Source Requirements

- **actinic metrology tools required**
  - ✓ ABI – actinic mask blank inspection
  - ✓ AIMS – aerial imaging microscope
  - ✓ APMI – actinic patterned mask inspection
  - ✓ in-situ AI – at scanner reticle cleanliness inspection

- **a very different source compared with Litho sources**
  - ✓ illumination field size - much smaller $(0.01 - 1\ \text{mm})^2$
  - ✓ power density on target - irradiance much higher
  - ✓ etendue - much smaller (~10^{-2} - 10^{-4} mm^2.sr)
  - ✓ source brightness - much higher ABI→AIMS→APMI – 10 →100 → >1000 W/mm^2·sr at-wavelength radiance

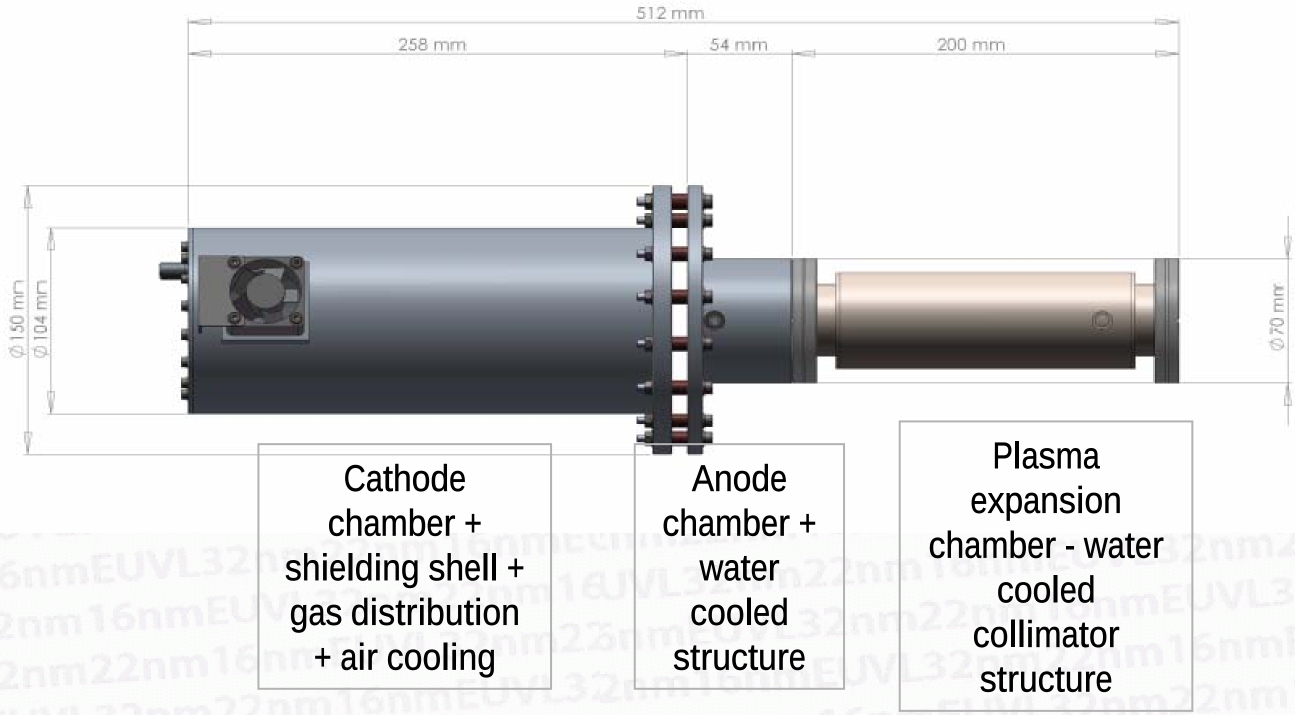
- **sufficient throughput** (300 mm Wafer)
  - ✓ mask blank inspection < 45 mn
  - ✓ off-line pattern mask inspection throughput of < **3** hr for full mask
  - ✓ at-line pattern mask inspection throughput of < **1.5** hr for full mask
  - ✓ aerial imaging throughput of < **1** hr for full mask (50 defects /site inspection)

- **different optics compared with Litho scanner**
  - ✓ small field size - diffractive optics
  - ✓ small NA on Mask to match projection optics

Source brighter than a synchrotron is needed -

The Core Technology i-SoCoMo™

CYCLOPS™ - GEN II cell



The emitting plasma in CYCLOPS™ is generated by a fast micro plasma pulsed discharge incorporating the i-SoCoMo™ technology, with an intrinsic plasma structure to provide photon collection and delivery. The Source module can be optimized to operate at high power or high irradiance.

Physical Dimensions:

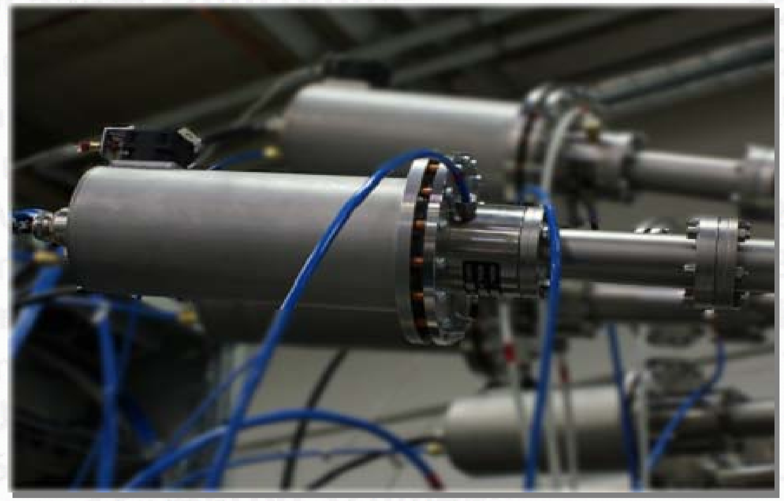
- Source : 150 mm diameter, 520 mm length, 7 kg
- Instrument rack : 1300 x 600 x 800 mm, 200 kg

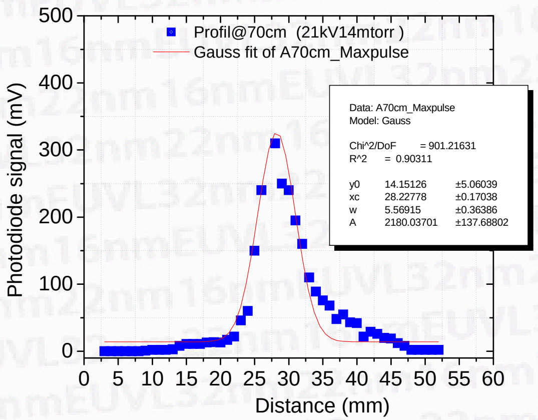
Source characteristics

- GEN II i-SoCoMo™

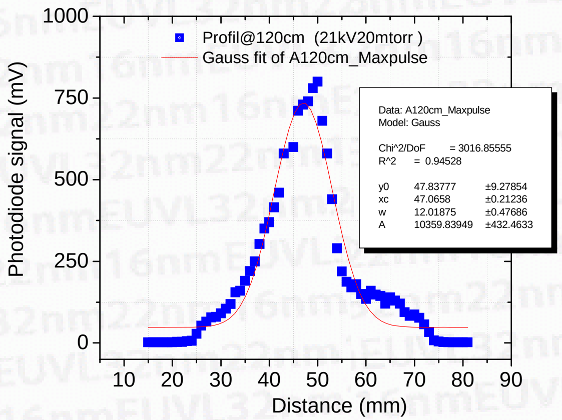
Measured performance

- stored energy 400mJ
- discharge in He/…/Xe admixture
- use SXUV20 Mo/Si filtered diode (IRD) with Al (110 nm) on Si3N4 (100 nm) filter
  = 3 nm EUV band (12.4 nm -15.4 nm)
- typical etendue 1.7 E-2 mm^2.sr





Scanned signal profile @ 70cm



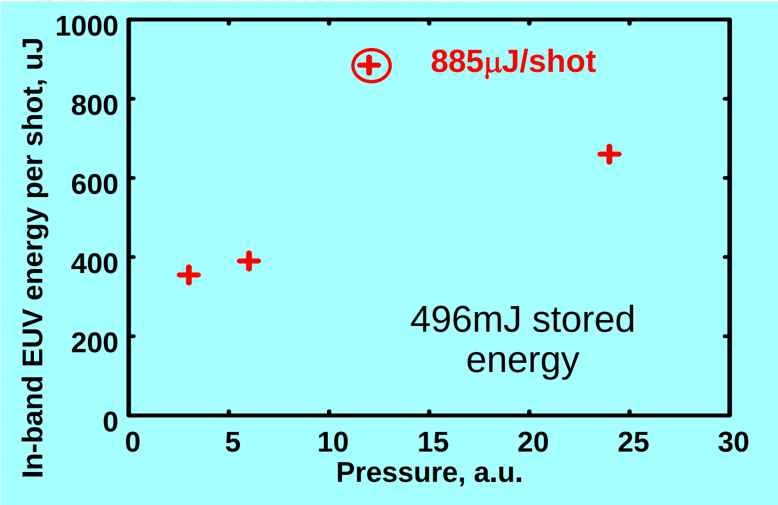
Scanned signal profile @120cm

Distance source to diode (cm)	Irrandiance @ 1kHz Ph/cm2/s	Beam FWHM (mm)	Radiation half angle divergence (deg)
70	5.7 E17	6.6	0.43°
120	8.7 E16	14.1	
Radiation solid angle =1.8 e-4 sr			

2010 International Workshop on EUV Sources UCD, Dublin Ireland

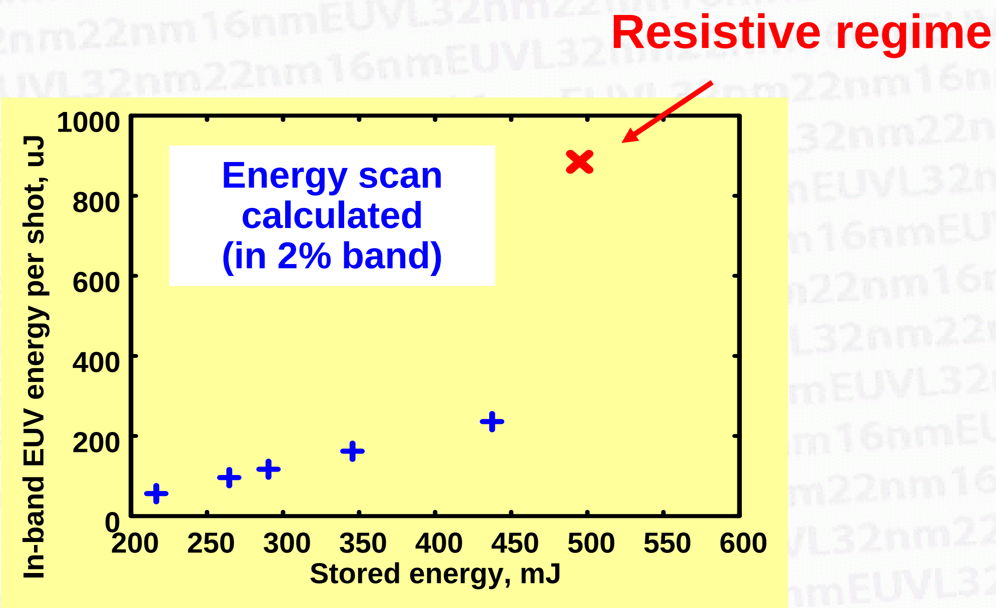
Gen II EUV Source

- characteristics & optimization from Z* modelling



Optimization by gas mixture pressure

EUV source scan by stored electrical energy

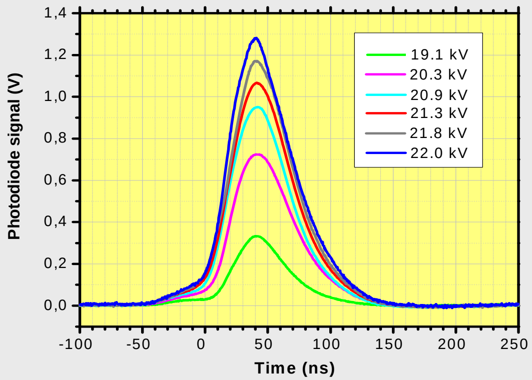


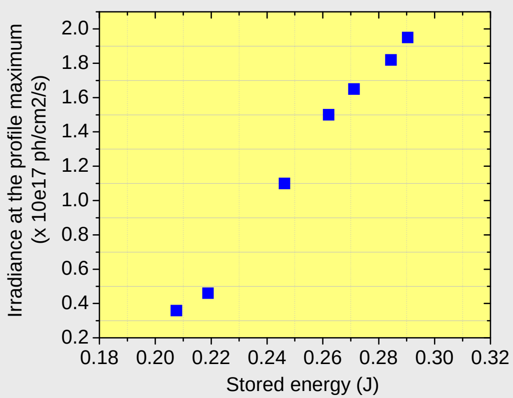
(for more details see poster: SergeyV.Zakharov et al)

Progress over the last six months

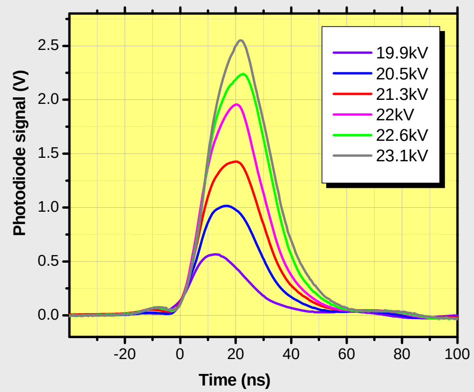
- irradiance vs stored energy

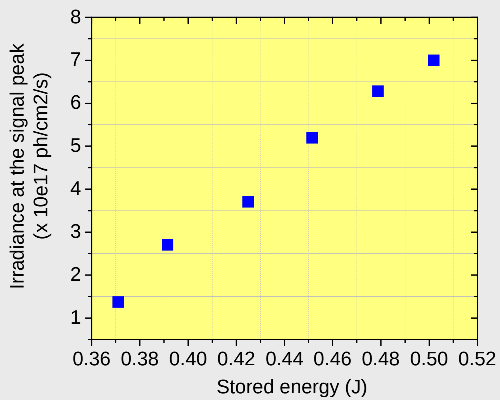
Results presented at SPIE February 2010





Current Results



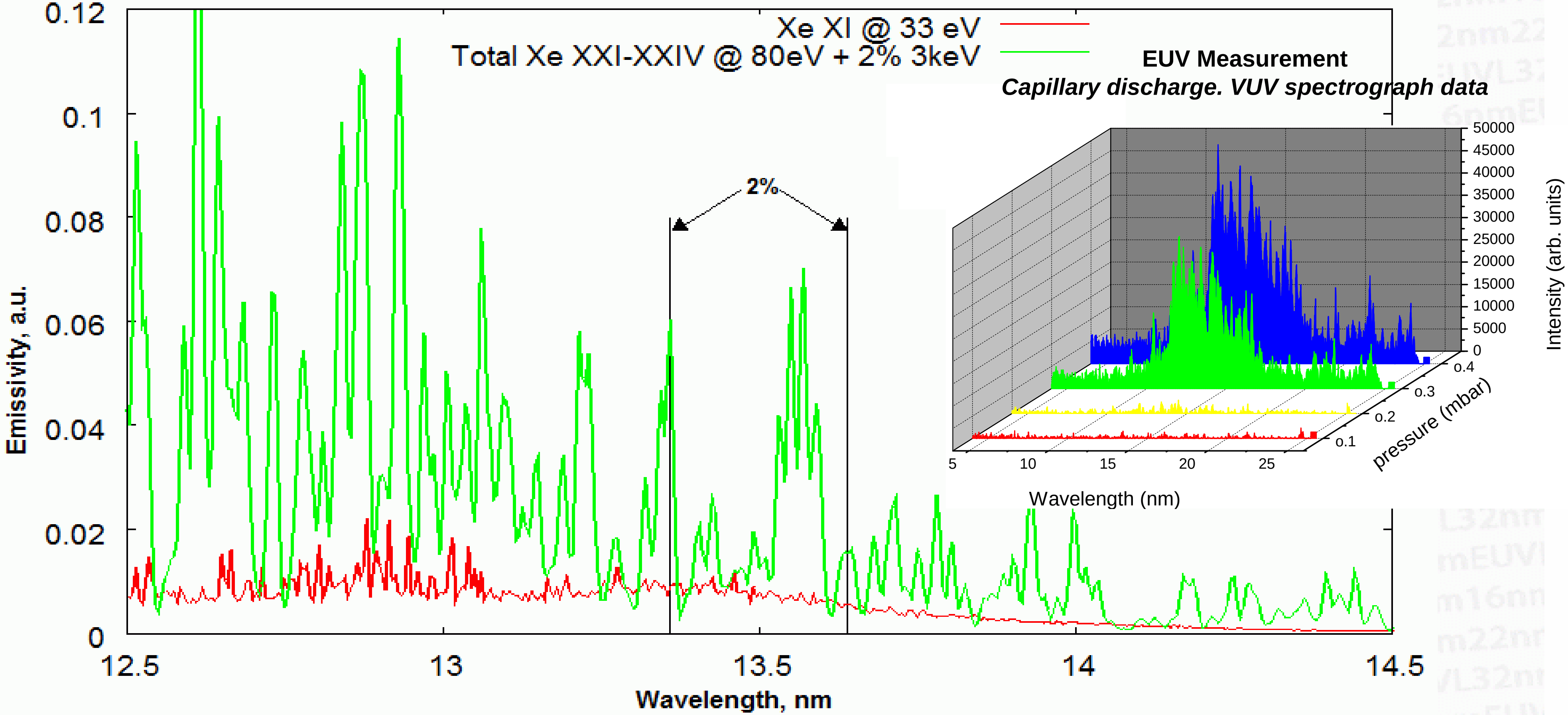


At same operating voltage

- ✓ **1.5 time increase on the stored energy**
- ✓ **Improvement on the gas mixture and flow rate**

- ✓ **2.5 fold increase in the irradiance**
- ✓ **2.5 fold increase on power**

EUV Emission of Highly Charged Xe Ions
- from e-beam triggered discharge plasma



Bright EUV emission in 2% band at 13.5 nm can be achieved from highly charged xenon ions in plasma with small percentage of fast electrons

(for more details see poster: Vasily S. Zakharov et al)

2010
International
Workshop on
EUV Sources
UCD, Dublin
Ireland

Multiplexing

- a solution for high power & brightness

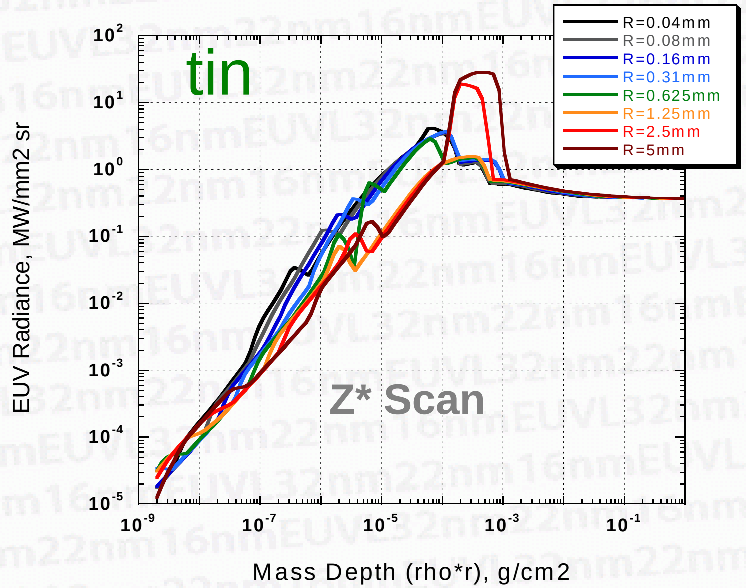
- Small size sources, with low enough etendue $E_1 = A_s \Omega << 1\ mm^2\ sr$ can be multiplexed.

- The EUV power of multiplexed N sources is

$$P_{EUV} \propto \sqrt{E \cdot N \cdot \Omega} \cdot \tau \cdot f$$

⇒ The EUV source power meeting the etendue requirements increases as $N^{1/2}$

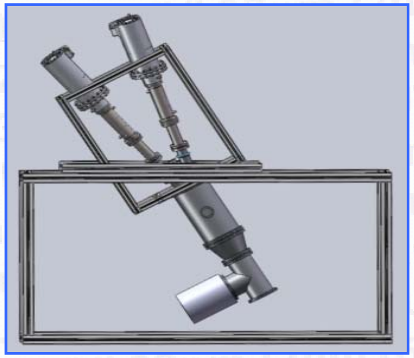
- This allows efficient re-packing of radiators from 1 into *N* separate smaller volumes without losses in EUV power

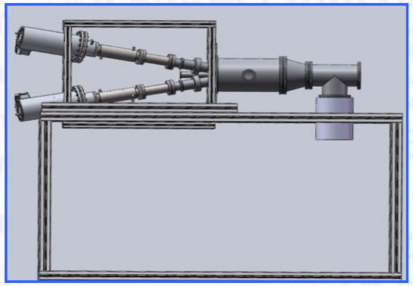


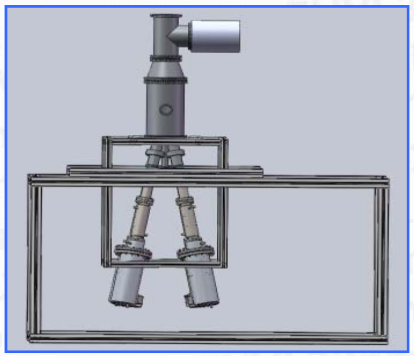
- **Spatial-temporal multiplexing:** The average brightness of a source and output power can be increased by means of spatial-temporal multiplexing with active optics system, totallizing sequentially the EUV outputs from multiple sources in the same beam direction without extension of the etendue or collection solid angle

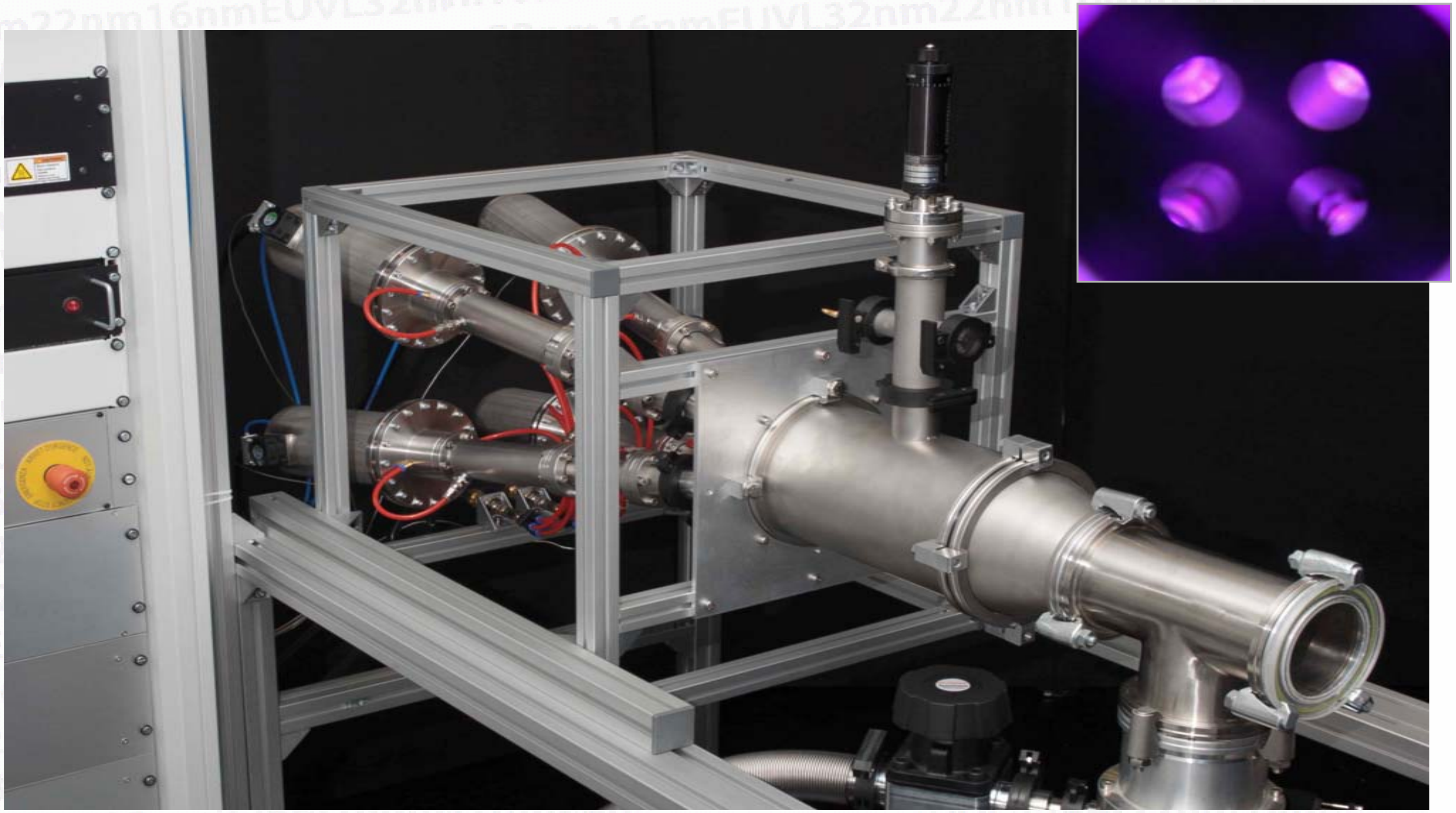
HYDRA^{4}-ABI™

prototype system







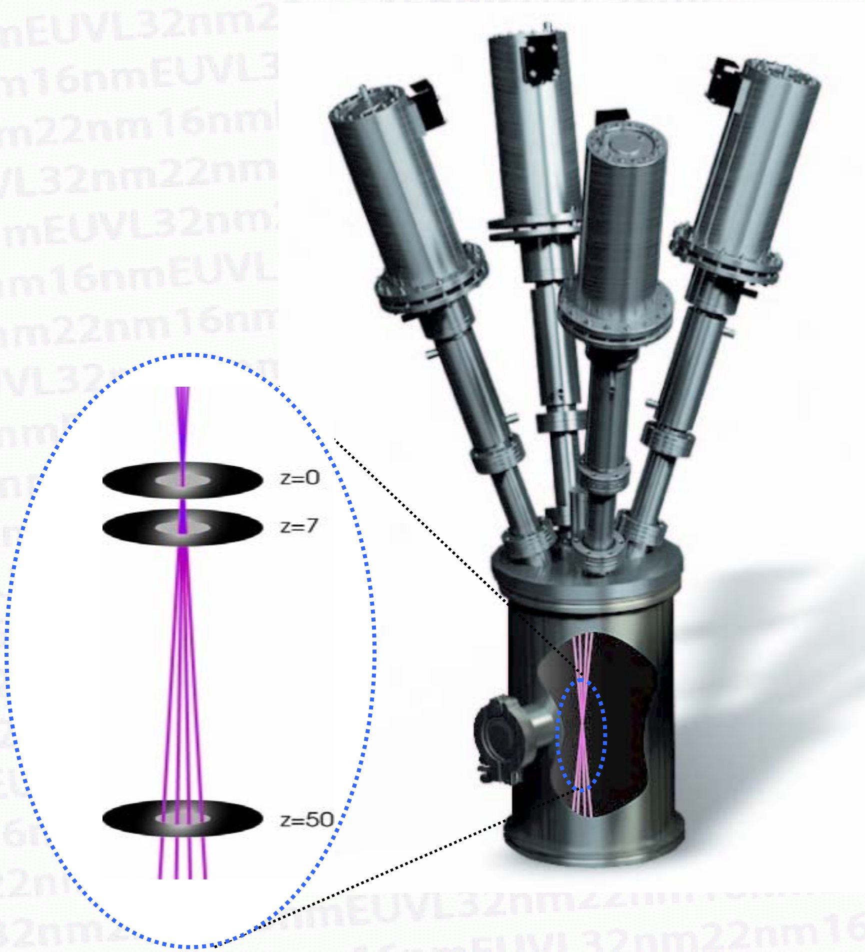


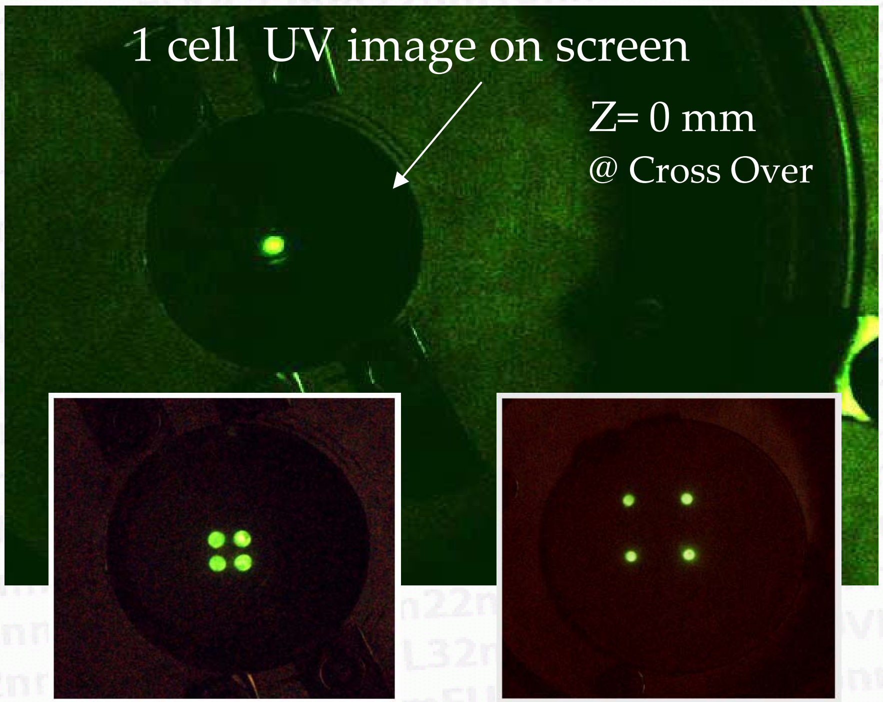
A compact EUV Source for Mask Blank Metrology

HYDRA^4-ABI™

- Spatial multiplexing

- Beam Distribution along Optical Axis
- Radiations observed on a fluorescent screen at various distance along the beam axis





Z= 7 mm

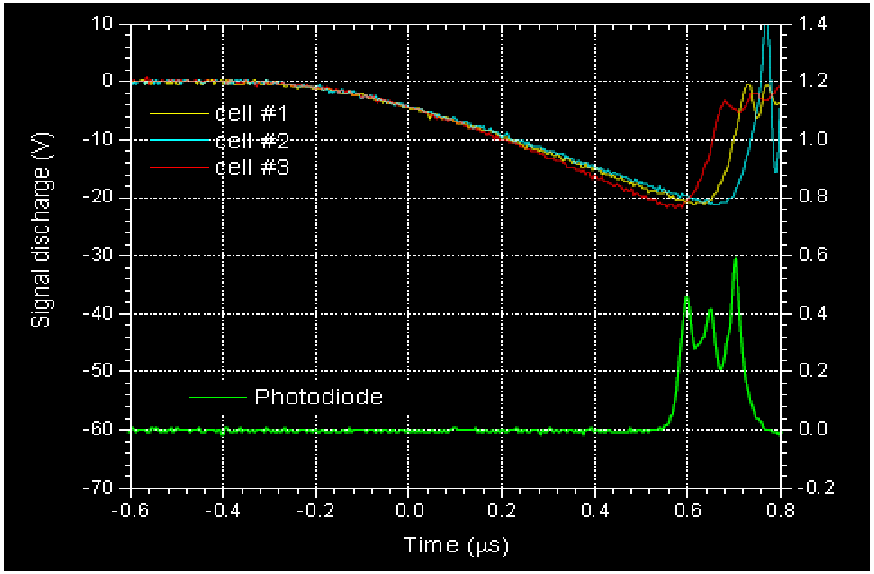
Z= 50 mm

All 4 sources operating simultaneously

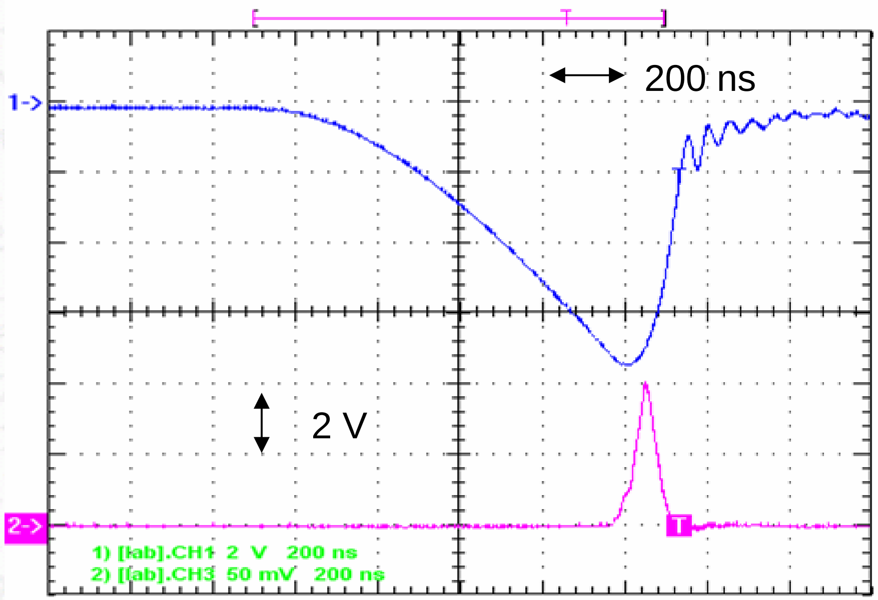
HYDRA4-ABI™

- Source multiplexing

- 4 Cells Simultaneous Operation @ 20 KV; 1 KHz
- Untriggered discharges within 100 ns
- Filtered (3 nm band) photodiode signals records



- 1 Cell discharge

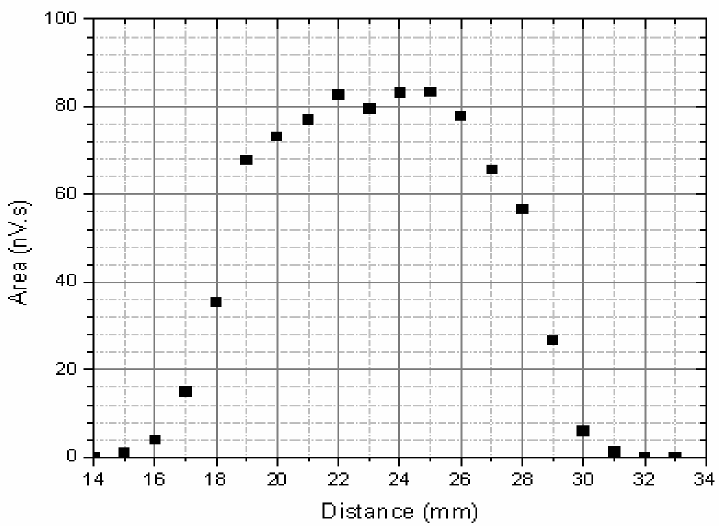


HYDRA⁴-ABI™

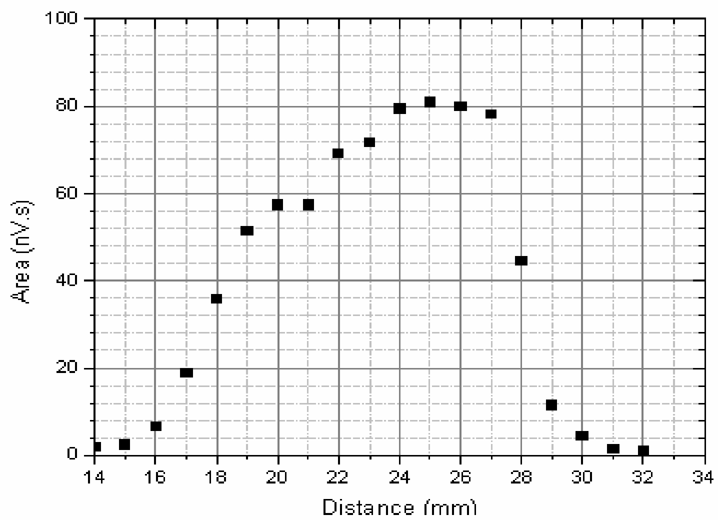
- Spatial multiplexing

- 4 cells operating @ 1 KHz @ 22 KV
- Cells capacity : 1.2nF each
- Operating Pressure ; 30mTorr

Profile scans recorded on SUXV 20A (Mo/Si) Diode (3nm EUV band) positioned @ 70 cm perpendicular to the optical beam axis



Summation of 4 single Beams



4 Beams simultaneous

9.6 10^{13} ph/pulse ➔ 1.4mJ/pulse ➔ 1.4 W @ 1 KHz

HYDRA^4-ABI™

- Product for Blank Inspection tool

Specifications

EUV performance:

- Wavelength : 13.5 nm
- Irradiance : 0,6 W@ IF
- Radiant Brightness : 60W/mm².sr inBand 2% @ IF
- Typical Etendu : 10^{-2} mm².sr
- Pulse repetition rate : 3 kHz
- Operation Gas : He + N_2 + Xe
- Source operating pressure : 60 mTorr typical
- Lifetime Time before service : 1 billions shots
- Source size : apertured to 2mm spot in each beam

Utility requirements:

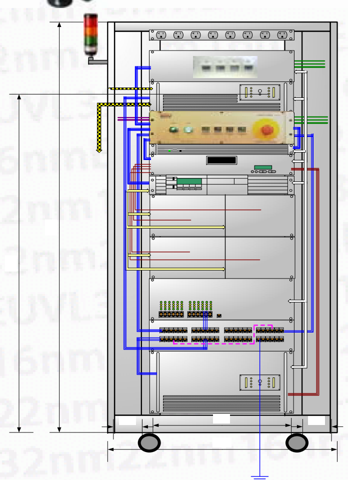
- Electrical : 380-400V, 3Ø, 50/60 Hz, 3x32A
- Cooling : Water cooled (8 litres per minutes, 15°C - 25°C inlet)
- He Ar Xe : 3 bar inlet

Physical Specifications:

- Source : 900 diameter, 650 mm length, 120 kg
- Instrument rack : 1760 x 1000 x 850 mm, 200 kg

Compliance:

- HYDRA^4- ABI™ : CE Mark, SEMI S2-0709

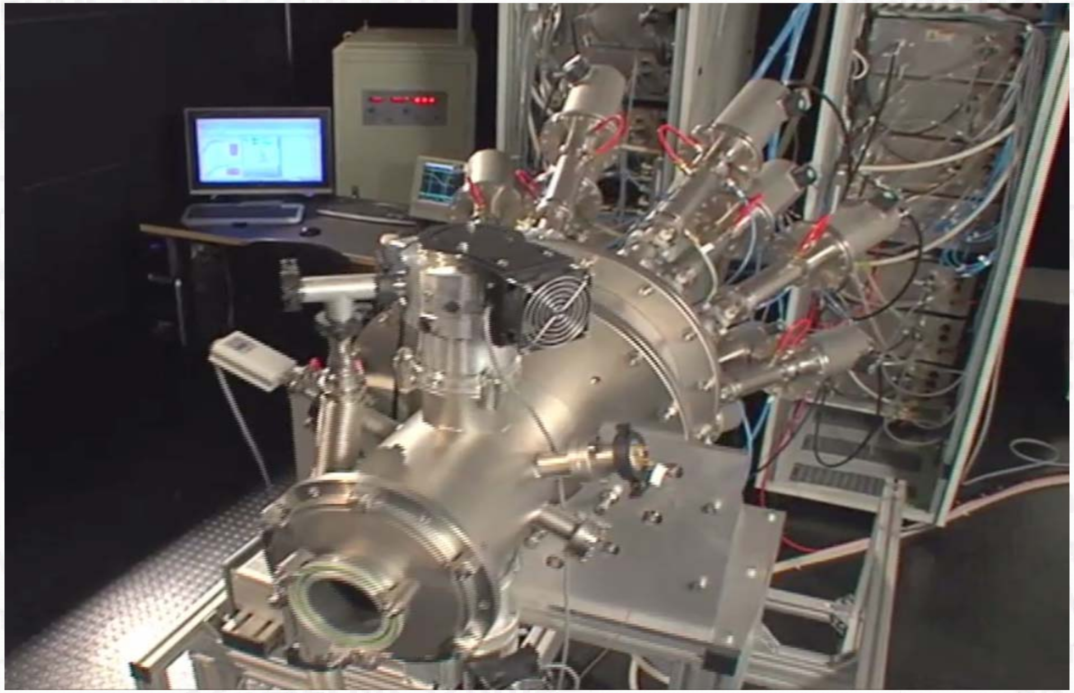


2010 International Workshop on EUV Sources UCD, Dublin Ireland

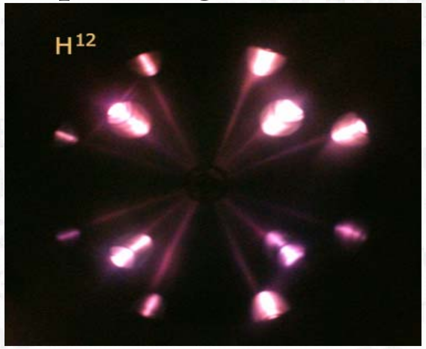
HYDRA^{12}-AIMS™

- Spatial multiplexing with variable sigma

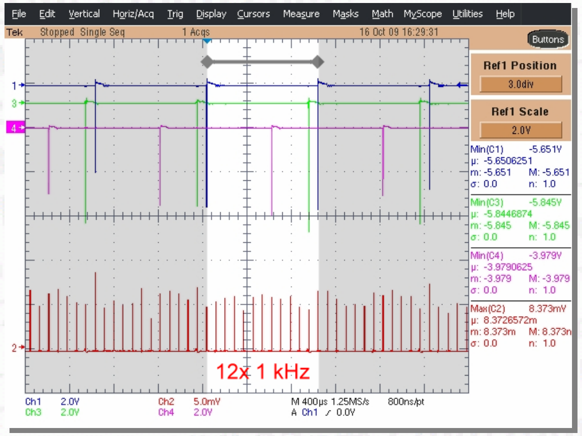
- prototype system



Viewing into the 12 Units operating @ 1KHz



12 Units operating sequentially @ 1KHz

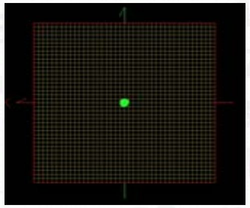


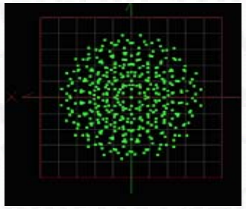
A EUV Source optimized for Aerial Image Measurements in Patterned Mask Metrology

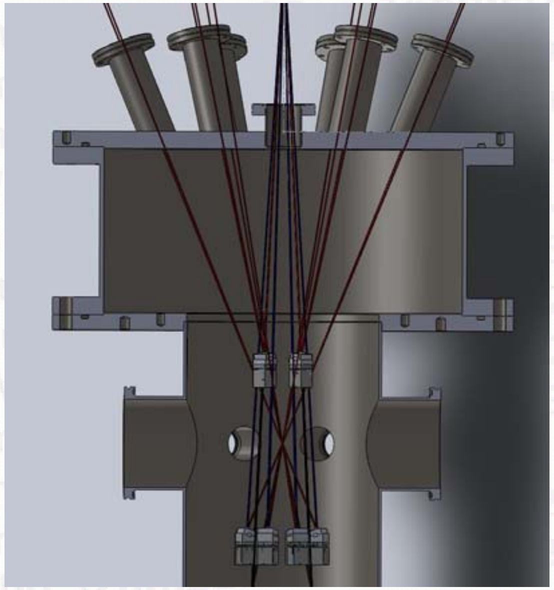
HYDRA[12]-AIMS™

- Spatial multiplexing with variable sigma

- Design Specifications
  - 100 W/mm².sr in-band 2% EUV radiant brightness
  - 2.4W at the IF
  - etendue - 2.4 10^{-2} mm².sr (50% fill pupil)
  - source area - 4 mm² / variable sigma
  - **optimized for aerial image measurements**
  - **12x** i-SoCoMo™ units, 5 kHz working each
  - no debris / membrane filter
  - **variable pupil fill and sigma**
- Current Status
  - system characterization
  - single unit optimization
  - ML mirrors modelling
  - life time components testing


curved ML


plane ML



2010 International Workshop on EUV Sources UCD, Dublin Ireland

ROADMAP

	EUV Source Projections	EUV Source Projections	EUV Source Projections	EUV Source Projections
Attribute	NanoUV	NanoUV	NanoUV	NanoUV
Date	Current	Mid-year 2011	Current	Year-end 2011
Type of source	HYDRA™-ABI		HYDRA™-AIMS	
Level of integration	ALPHA DEMO	BETA PRODUCT	ALPHA DEMO	BETA PRODUCT
Demonstrated operating time	1b shots	5b shots	1b shots	5b shots
Wavelength (nm)	13.5	13.5	13.5	13.5
Measured average EUV power (13.5 nm, 2 % FWHM), after collector (W)	0.6 (4 units@3 kHz, to include 1 ML)	0.6	0.8 (12 units@3kHz to include 1 ML)	2.4
Source area (mm^2)	7	TBD	4	variable sigma
Etendue of source output (mm^2 sr)	1.00E-02	1.00E-02	2.40E-02	2.40E-02
Max. solid angle to system (sr)	2.00E-02	2.00E-02	TBD	TBD
EUV brightness (13.5 nm, 2 % FWHM) ($Wmm^{-2}sr^{-1}$)	60	60	33	100
Repetition rate (kHz)	3	3	<5	5
Integrated energy stability (%)	3% rms	0.3% rms	3% rms	0.3% rms
Plasma size stability (mm)	0	0	0	0
Plasma position stability (mm)	0	0	0	0
Source cleanliness (10% throughput loss for ML)	1b shots	25b shots	1b shots	25b shots
Spectral purity				
20 - 130 nm	<1E-3	<1E-3	<1E-3	<1E-3
130 - 400 nm (DUV/UV)	<1E-3	<1E-3	<1E-3	<1E-3
>= 400 nm (IR/VIS), including 10.6 mm	<1E-3	<1E-3	<1E-3	<1E-3

SUMMARY

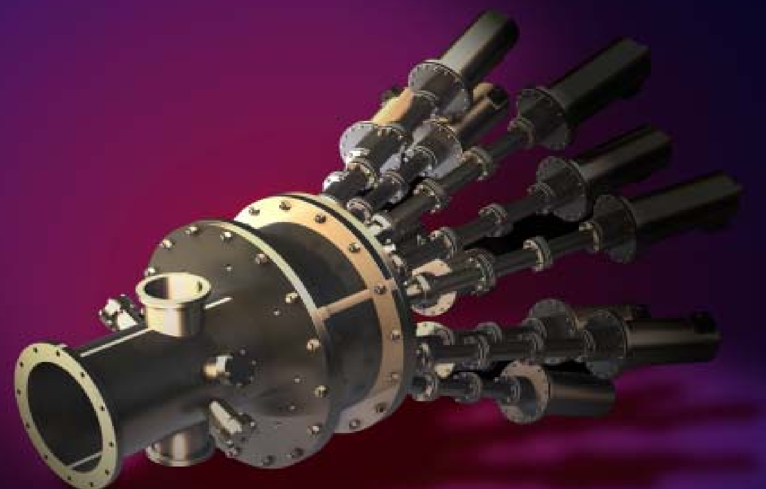
- The very high brightness of the light sources necessary for inspection are beyond what is currently available. The self-absorption of radiation limits the in-band EUV radiance of the source plasma and makes it difficult to attain the necessary brightness and power from a conventional single unit EUV source.
- NANO-UV is delivering a new generation of compact EUV light sources with an intrinsic photon collector, the i-SoCoMo™ concept, where a micro plasma pulsed discharge source is integrated to a photon collector based on an in situ active plasma structure. The source is characterized by high brightness, low etendue and very high irradiance, at moderate output power.
- Time resolved measurements show substantial power/ irradiance increase achievable in GEN II cell compared with previous data
- Extrapolation suggests the source can deliver in 2% band around 13.5 nm ~ 1.6W power to a spot of under 1 cm diameter ~ 16W average at 3 kHz, with 0.4J stored energy per pulse
- Etendue increases rapidly with increasing energy stored and EUV output but remains < 10^{-2} mm^2.sr at the maximum parameters tested
- Using a number of such source modules, we are developing light sources with the requisite brightness and power to address the mask metrology needs, with spatial and temporal multiplexing – the HYDRA™ design.

nano V

Acknowledgement

- R&D team & collaborators
  - Pontificia Universidad Catolica de Chile
  - RRC Kurchatov Institute, Moscow, Russia
  - Keldysh Institute of Applied Mathematics RAS, Moscow, Russia
  - University College Dublin
  - King's College London
- Sponsors - EU & French Government
  - ANR- EUVIL
  - FP7 IAPP
  - OSEO-ANVAR
- RAKIA

– Ultra high brightness
– modular construction
– small foot print
– low cost of ownership
– adaptable to user needs



A New Technical Capability Arising